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Transient dystonias revisited: a comparative study of preterm and term children at 2½ years of age

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Minor neurological dysfunctions (MND) have frequently been reported as an outcome of preterm birth. Behavioural and learning difficulties are a known feature, but coordination problems are especially described in preterm infants at later ages. All preterm infants in our study were born with a gestational age of <32 weeks and a birthweight of <1500 g. The aim of the study was to determine if in a normal clinical situation, children at risk for developing coordination problems could be detected by focusing particularly on their spontaneous, although elicited, motor performance. Forty-two children of 2 years 6 months of age were studied of whom 25 were 'low-risk' preterm and 17 were born at term. All children had been followed up since birth. In a structured, free-field situation the quality of body rotation, spontaneous reaching-out, and manipulation during parts of the Bayley Developmental Test were observed and videotaped. Body rotations were scored on a 2-point scale, and arm and hand functions on a 3-point scale. Most preterm infants showed non-optimal body rotations and borderline or non-optimal arm and hand functions in contrast to most term children. A clear connection was found between less optimal body rotations and poor arm and hand functions. Retrospectively, poor arm and hand functions at 2 years 6 months seemed to be related to those at 39 weeks. At the age of 39 weeks a clear relation had been found between poor postural control (many preterm infants could not sit independently) and earlier hyperextension of the trunk at 18 weeks and quality of arm–hand functions. In the present study at 2 years 6 months a correlation with the former hyperextension could no longer be found, but there was a significant relation between poor trunk rotation and arm and hand function and the earlier arm and hand functions at 39 weeks.

Many preterm infants are known to develop coordination, learning, and behavioural problems when they grow older (Ens-Dokkum et al. 1983, Hadders-Algra et al. 1988b, Weisglas-Kuperus et al. 1994). A recent study in the Netherlands determined that 19% of a population of 9-year-old children born preterm were clumsy and/or attended special education, and 57% needed extra help at school (den Ouden et al. 1998). The cause of these problems has not been fully elucidated. Often follow-up studies comprise a very heterogeneous group: studies have included infants with different medical histories and there is no real agreement on what constitutes normal neurological development in preterm infants (de Groot 1992a). Several studies stress the importance of neuromotor problems as an explanation for the link between preterm birth and learning disability. In a study of healthy preterm infants, Wijnroks (1994) found that problems in postural control at early ages were most predictive for the cognitive and attentional state of these infants at the age of 2 years. Hadders-Algra and coworkers (1988b) pointed out that children with minor neurological dysfunctions (MND) are vulnerable to cognitive problems and school failure. Complex MND, if characterized by poor quality of movement or coordination problems, showed a unique association with preterm birth (Soorani-Lunsing et al. 1993). Barinaga (1996) postulated that coordination problems observed in preterm infants, as well as cognitive problems, may be mutually linked by a deviant function of the cerebellar system.

Other studies have claimed that coordination problems in preterm children are the expression of earlier transient dystonias. The concept of transient dystonia was first put forward by Drillien in 1970. She reported abnormal signs in the early months of life that disappeared after 1 year and, therefore, considered them transient. Dystonia has been a much disputed term and has often been used to indicate definite neurological pathology. In other studies the transient dystonias, particularly the hyperextension of the trunk, have indeed been considered transient when there was no sign of additional neurological pathology (Touwen et al. 1983). Later this fact was contradicted (see de Groot 1992a, 1993). The dystonias recognizable as hyperextension may not always be a sign of major pathology, such as in cerebral palsy, but hyperextension interferes with the acquisition of adequate postural control which is essential for a good motor performance and social interaction.

The definition we prefer for this phenomenon is that of faulty muscle power regulation. This is characterized and observed by a discrepancy between the active muscle power generated by spontaneous or elicited movements by the infant and the passive muscle tone which is felt by manipulating the infant in a relaxed and quiet state. For fluent movement these two components of muscle power should balance each other (for details see de Groot 1992a, 1993). These discrepancies have been well described and are clinically recognizable and intimately linked to, for example, hyperextension of trunk and shoulders leading to poor postural control (Georgieff et al. 1986, Gorga et al. 1988, de Groot et al. 1992b). In turn, dysfunctional postural control is considered to be one of the key symptoms in children with major motor deficits (Aicardi et al. 1998). But even when less prominent dysfunctional postural control will influence

*North American usage: mental retardation.

motor learning, which is the adaptation to the demands of the environment, such as in reaching for an object. More fundamental research has shown that postural control in preterm infants is temporarily disorganized and interferes with normal motor and cognitive development (Van Der Fits et al. 1998). Clinically, early hyperextension has been shown to hamper preterm infants in getting into the sitting position and to affect trunk rotation during sitting (de Groot 1995). Optimal postural control is a prerequisite for well-coordinated hand function which, for example, later becomes necessary for good writing skills (Smits-Engelsman 1991, Von Hofsten 1993).

In a comparative study of hand function in healthy preterm and term infants, Plantinga and colleagues (1997) showed that 39-week-old low-risk preterm infants demonstrated qualitatively less optimal hand function, mainly in the sense of coordination problems between flexor and extensor muscles of the fingers and poor anticipation and timing in grasping an object. This outcome was strongly related to the former hyperextension of the trunk at 18 weeks. In a later study of early walking patterns, subtle coordination problems involving a disturbed balance between flexion and extension were found in these children: they were visible during a task such as picking up a toy from the floor (de Groot et al. 1997). Thus, it was speculated that (see de Groot et al 1997) muscle power irregularities, often called transient dystonias, evolve and change in character over time and do not prevent the development of useful function. Discrepancies found between flexor and extensor muscles seem not to be restricted to the trunk only, observable as hyperextension, but seem to be of a more global character only detectable when the child reaches a certain age and a new function is established.

In this prospective study we reexamine a group of well-defined preterm children at the age of 2 years 6 months and compare them with children born at term. The infants in this study were carefully selected for having no known brain damage or other major paediatric or neurological problems in an effort to study only the effects of being born preterm. We focused on qualitative differences in spontaneous motor behaviour between the preterm and term children by assessing body rotations, considered as a measure of modified postural control at this age, and the quality of arm and hand functions. The main aim of this study was to see whether earlier discrepancies were indeed transient or if they could still be observed in preterm children at the age of 2 years 6 months. This is important in order to be able to select those children most in need of intervention.

Table I: Participants

Infants	*n*	*GA (wk)*	*Birthweight (g)*
Term, Mean (SD)	17	40 (2)	3522 (287)
Preterm, Mean (SD)	25	30 (4)	1592 (416)

GA, gestational age.

Method

PARTICIPANTS

The study group consisted of 45 children: 25 were born

Table II: Clinical data for preterm infants

Infants	*GA[b], weeks/days*	*Birthweight status*	*Apgar 1'/5'*	*Ventilatory support, type/days*	*Clinical events*
1	34/3	P_{25}	8/10	CPAP/1	No
2	33/3	P_{50}	6/10	No	No
3	33/5	P_{50}–P_{75}	9/10	No	No
4	33/3	P_{25}–P_{50}	9/10	CPAP/1	No
5	33/6	P_{75}	9/10	CPAP/2	Mild IRDS
6	33/3	P_{25}	3/9	02 mask/<1	No
7	33/0	P_{25}–P_{50}	9/8	ETT/2b, CPAP	Pneumonia
8	33/0	P_{25}–P_{50}	4/8	CPAP/1	Mild IRDS
9	31/3	P_{50}–P_{75}	8/8	CPAP/1	No
10	32/3	P_{50}–P_{75}	8/8	CPAP/1	No
11	31/0	P_{50}–P_{75}	7/10	ETT/2, CPAP/1	Pneumonia
12	28/5	P_{25}	9/10	ETT/3, CPAP/7	Apnoeas
13	32/3	P_{50}–P_{75}	8/9	No	Apnoeas, bradycardias
14	28/5	P_{25}–P_{50}	8/10	No	No
15	31/0	P_{25}–P_{50}	–/8	CPAP/4	Mild IRDS
16	31/3	P_{25}–P_{50}	9/10	No	No
17	32/0	P_{50}–P_{75}	–/10	No	No
18	33/3	P_{50}	9/10	No	No
19	34/3	P_{25}–P_{50}	9/10	No	No
20	29/4	P_{50}–P_{75}	7/10	CPAP/1	Apnoeas
21	31/5	P_{50}–P_{75}	–/8	CPAP/1	No
22	34/0	P_{5}–P_{10}	9/10	CPAP/2	No
23	33/6	P_{5}	8/9	No	No
24	34/0	P_{5}–P_{10}	8/9	No	No
25	31/2	P_{5}–P_{10}	7/9	CPAP/1	No

GA, gestational age at birth; P, percentile growth; CPAP, continuous positive airway pressure in days; ETT, endotrachial ventilation; IRDS, infant respiratory distress syndrome.

preterm and 20 were healthy term children. All were white and were singletons when they entered the study. Three term infants had to be excluded from the study, due to missing data.

The preterm population was recruited from the intensive care unit of the Academic Hospital of Vrije Universiteit, the Netherlands and other regional hospitals near Amsterdam. Gestational ages of the preterm infants ranged from 27 to 34 weeks. The preterm group comprised infants assessed to be at low risk for later developmental problems. No child had any evidence of hypoglycemia and infants were not recruited if they had congenital abnormalities, severe periventricular hemorrhage (Papile grade III and IV), periventricular leukomalacia, or asphyxia. Children were not selected if they showed karyotypic abnormality, foetal infection, or malformation. Dating of pregnancy was based upon reliable maternal information and when necessary on the outcome of an early ultrasound. Neonatal status of the children is given in Table I. All preterm infants had a full neurological examination at 35 weeks' postmenstrual age and at term age before entering the study. (For clinical data see Table II). The assessment of the children born

Table III: Individual profiles of quality of arm and hand function and body rotations of preterm and term children at 2 years 6 months of age

Child	*RA*	*RH*	*CO*	*AM*	*SMIR*	*SMIA*	*HES*	*HOS*	*Yoke*	*Rotation*
Preterm										
1	●	●	●	◗	○	◗	○	◗	+	–
2	○	○	○	○	○	○	○	◗	–	–
3	●	○	◗	○	○	◗	○	◗	+	–
4	●	●	◗	○	○	●	◗	●	+	–
5	●	●	●	◗	○	◗	◗	◗	+	–
6	○	○	◗	○	○	○	○	◗	–	+
7	○	○	○	○	○	○	○	◗	–	+
8	◗	●	●	◗	○	◗	○	◗	+	–
9	●	●	●	●	○	●	◗	◗	+	–
10	◗	●	●	◗	○	◗	○	◗	–	–
11	○	◗	○	○	○	○	○	◗	–	+
12	◗	◗	◗	◗	○	◗	○	●	+	–
13	●	●	●	○	○	◗	◗	◗	+	–
14	○	◗	○	○	○	○	○	◗	–	+
15	◗	◗	●	◗	○	◗	○	◗	+	–
16	●	●	●	○	◗	●	○	◗	+	–
17	○	○	○	○	○	○	○	○	–	+
18	○	●	◗	○	○	◗	○	◗	+	–
19	◗	●	◗	○	○	◗	○	◗	+	–
20	○	○	○	○	○	○	○	○	–	–
21	◗	●	◗	○	○	◗	○	○	+	–
22	○	○	◗	○	○	◗	○	◗	+	–
23	●	●	●	●	◗	●	○	●	+	–
24	○	○	○	○	○	◗	○	○	–	–
25	○	○	○	○	○	○	○	◗	+	–
Term										
1	○	○	○	○	○	○	○	○	+	–
2	○	○	○	○	○	○	○	○	–	+
3	○	○	○	○	○	○	○	○	–	+
4	○	○	○	○	○	○	○	○	–	+
5	○	○	○	○	○	○	○	○	–	+
6	○	◗	◗	○	○	○	○	◗	–	+
7	○	○	○	○	○	○	○	○	–	–
8	○	○	○	○	○	○	○	○	–	+
9	○	○	○	○	○	○	○	○	–	+
10	○	○	○	○	○	○	○	○	–	+
11	○	◗	○	○	○	○	○	○	–	+
12	○	○	○	○	○	○	○	◗	+	–
13	○	○	○	○	○	○	○	◗	–	+
14	◗	○	○	○	○	○	○	○	–	+
15	○	○	○	○	○	○	○	○	–	–
16	○	○	○	○	○	○	○	○	–	+
17	◗	●	◗	○	○	○	○	○	+	–

○, optimal; ◗, slightly deviant; ●, clearly deviant; + present; – absent. RA, muscle power regulation arm; RH, muscle power regulation hand; CO, coordination; AM, associated movements; SMIR, synergic movements interlimb; SMIA, synergic movements intralimb; HES, heterolateral support; HOS, homolateral support; Yoke, non–optimal rotation, Rotation, optimal rotation.

at term started at birth or within one week. Children were included in the study only if they had a normal neurological assessment (Touwen 1976, Prechtl 1977, de Groot 1992a). The control group of term infants was selected from midwife indexes in the region. Their gestational ages ranged from 38 to 40 weeks.

Mothers were aged between 18 and 40, had no history of alcoholism, and none had been smoking excessively. All had had at least elementary or higher education.

PROCEDURE

All infants (preterm and term) in this study had been followed up from term age and thereafter at 6, 12, 18, and 39 weeks' corrected age. Age-adequate neurological examinations were carried out which put extra emphasis on the development of muscle power (de Groot 1992b). At the age of free walking (walking experience 14 days) a free-field assessment was done to determine the quality of their walking patterns (for details see de Groot et al. 1997). The last assessment in our hospital was done at the age of 2 years 6 months and comprised an overall paediatric and neurological examination and a Bayley Developmental Test.

For this specific study only two items from the Bayley Developmental Test – the Blue Puzzle and Pegboard tests – were used (Van der Meulen and Smrkovsky 1983). Emphasis was on the motor behaviour of the child.

Children were placed on a child's chair at a table with the test material in front of them in such a way that trunk rotations and hand function could easily be observed. When the children were in a cooperative state they were asked to do the puzzle. Assessments were videotaped and the quality of movement was judged retrospectively by two independent observers (who were unaware of the child's perinatal history; Cohen's Kappa 0.94). Data of the children were than compared retrospectively with their data of 39 weeks (corrected age; for details see de Groot et al. 1995, Plantinga et al. 1997).

INSTRUMENT AND SCORING SYSTEM

Body rotation was judged as the absence or presence of a 'yoke-movement'. A yoke-movement is described as a deviant shoulder movement during forward reaching at which the ipsilateral shoulder moves forward and at the same time the contralateral shoulder moves backwards; as if a yoke is placed on the shoulders. The shoulder blades seem to be fixed in a retracted position. The rotation is restricted and has an en-bloc appearance. (Hempel 1993)

The quality of the body rotation was scored on a 2-point scale: absence of the yoke-movement was considered to be an optimal outcome (0) while the presence of the yoke movement resulted in a non-optimal score (2). Arm and hand function were measured by the same instrument used in an earlier study of the same population at age 39 weeks and consisted of the following items: muscle power regulation of the arm, muscle power regulation of the hand, coordination, associated movements, synergic movements intralimb, and homolateral support when reaching and grasping. (Plantinga et al. 1997).

For our study at 2 years 6 months, two extra items were included: synergic movements interlimb and heterolateral support when reaching. Synergies act as basic units in the regulation of control of movement to reduce control parameters. They produce rather fixed patterns of movement and can span many joints. When more voluntary movements occur, synergies should be broken up to make more dissociated, isolated movement possible. At younger ages synergies serve as a form of postural control and fixation in space. In pathological circumstances, synergies are superimposed on voluntary movement and make them impossible or less fluent and restricted. For correlations with the data at 39 weeks of age these two items were excluded. All test items are listed in Table I. The items were scored on a 3-point scale (0, optimal; 1, slightly deviant; and 2, clearly deviant outcome; see Appendix for specified items and criteria). Internal consistency of the instrument used at 2 years 6 months for the qualitative arm and hand function resulted in a Cronbach's alpha of 0.89. The outcome of arm and hand function was summed and cut-off scores were used to categorize the children as showing optimal (0 to 3), borderline (4 to 8), or non-optimal (9 to 13) arm and hand functions.

STATISTICAL ANALYSIS

For the outcomes at 2 years 6 months the following analyses were done. To compare the body rotations in children born preterm and at term a Mann–Whitney U test was used; t-tests were used to compare arm and hand functions between preterm and term children in clusters and also per item. For correlations between body rotation and arm and hand function, Spearman's correlation test was performed. The same test was used to compare data at 2 years 6 months with hyperextension at 39 weeks of age. Pearson's correlation test was performed to compare arm and hand function at 2 years 6 months and at 39 weeks. For all tests a preset alpha of 0.05 was used.

Results

At the age of 18 weeks (corrected) many preterm infants (25 of 31) had been showing increased or high active muscle power of the trunk compared with only six of 19 term

Table IV: Comparison of arm and hand functions in preterm infants at 39 weeks and 2 years 6 months

2 years 6 months	*39 weeks*		
	Optimal	*Borderline*	*Non-optimal*
Optimal	6	2	1
Borderline	4	3	1
Non-optimal	0	2	3

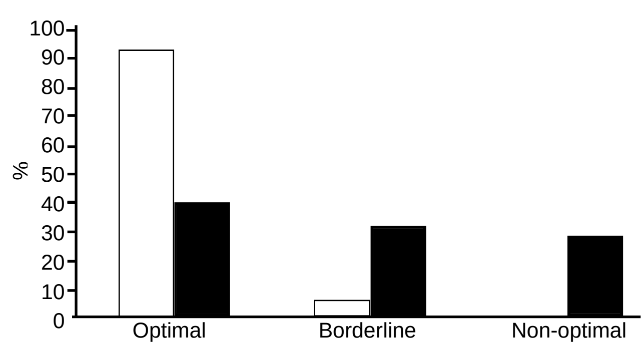

Figure 1: *Results of arm and hand functions for preterm and term infants at 2 years 6 months. □, term; ■, preterm.*

infants. Preterm infants had shown overextension when held in ventral suspension and did not show an adequate traction response but had the tendency to stand up during this test (de Groot et al. 1992b, Plantinga et al. 1997).

At age 39 weeks (corrected) half of the preterm infants (18 of 36) could not sit by themselves whereas all term infants ($n=20$) could sit independently. Trunk rotations were measured with the infant sitting freely (not leaning) on the mother's lap, supported by the pelvis only. Trunk rotation was elicited by making the infant follow an object. Rotation round the body axis was restricted, suggesting these preterm children needed to generate a higher activity of active extension in order to fix themselves in an upright position (de Groot et al. 1995). Preterm infants with problematic postural control also displayed significantly poor quality of arm and hand function, poor coordination of flexor–extensor muscles, and anticipatory shaping of the hand and excessive associated movements of the arm (10 preterm infants scored optimal, 13 borderline, and eight non-optimal hand function; Mann–Whitney U test $p=0.001$). At this age a correlation was found with earlier hyperextension of the trunk at 18 weeks (Spearman's $r=0.36$, $p=0.02$; $n=31$; Plantinga et al. 1997).

At the age of 2 years 6 months the individual profile of outcomes is given for each child (Table III). Six children could not be judged for body rotation (two term and four preterm children) and were considered as missing values. This was caused by the faulty placing of the children at the table: they were too near for proper observations to be made. Infants born preterm showed significantly less optimal body rotations than the term group. Of 21 preterm children, 16 showed yoke-movements compared with only three of 14 term children (Mann–Whitney U test, $p=0.007$).

Children born preterm also showed less optimal arm and hand function relative to the term children at this (corrected) age. Of 25 preterm children, only 10 showed optimal arm and hand function, eight were judged as borderline, and seven were in the non-optimal group (Fig. 1). Of 17 term children, 16 were categorized as optimal and only one term child was judged to be performing with a borderline arm and hand function. No term infants were in the non-optimal group. This difference was significant ($df=39$, $p=0.0001$).

Specific items that the preterm infants scored lower on were all related to muscle power regulation: muscle power regulation of the arm ($p<0.01$); muscle power regulation of the hand ($p<0.01$); coordination ($p<0.01$); synergic movements intralimb when reaching and manipulating ($p<0.01$); associated movements when reaching and manipulating ($p<0.05$); and heterolateral support when reaching and manipulating ($p<0.01$). A strong correlation was found between the quality of the body rotation and the quality of arm and hand function (Spearman's r, $p<0.01$).

To examine the relation between arm and hand function at 2 years 6 months and 39 weeks, only 22 preterm infants could be compared due to missing data at 39 weeks. A correlation was found ($p=0.05$). Comparison on the individual level revealed that arm and hand function of most preterm infants had remained the same: six of the nine children with optimal arm and hand function at 2 years 6 months had shown optimal function at 39 weeks. However, shifts appeared: of 10 children with an optimal outcome for arm and hand function at 39 weeks, four were in the borderline category at 2 years 6 months. In other children judged as non-optimal at 39 weeks, arm and hand functions had improved in one of the five child to 'borderline' and in one child to 'optimal' at 2 years 6 months. Of seven children belonging to the 'borderline' category at 39 weeks, two children showed improvement and moved to the 'optimal' category, only two other children became worse and were now judged as 'non-optimal' for arm and hand function (Table IV).

No significant correlation between the quality of body rotation at the age of 2 years 6 months (corrected) and earlier hyperextension of the trunk at the age of 39 weeks (corrected) could be found, nor was there a significant correlation between the quality of arm and hand function at 2 years 6 months and hyperextension at 39 weeks.

Discussion

Children born preterm showed qualitatively less optimal body rotations and arm and hand function at the (corrected) age of 2 years 6 months when compared with children born at term.

Sixteen of the 21 preterm children showed yoke-movements, compared with three of the 14 term children. In this study no relation could be found with earlier hyperextension of the trunk, in contrast with outcomes at the age of 39 weeks when body rotations were still hampered by hyperextension of the trunk (de Groot 1995).

Concerning arm and hand function, 15 of the 25 preterm children showed poor arm and hand function compared with only one child born at term. The items on which preterm children scored significantly lower indicated that these children had problems in adequately coordinating their muscle power (muscle power regulation of the arm, muscle power regulation of the hand, coordination, synergic movements intralimb, associated movements). To reduce poor coordination and poor postural control the children seemed to stabilize themselves by fixing the trunk and blocking rotations by too much extension, observable as the yoke-movement. Van der Fits and coworkers (1998) showed in an experimental study of healthy preterm infants deviances in postural adjustments during reaching movements, compared with term infants. In these preterm children, EMGs showed an excess of postural activity, different latencies in abdominal versus back muscles and neck muscles, and an inability to modulate postural responses to task-specific conditions, such as arm-movement velocity. Discrepancies in muscle power are a major influence in many aspects of development in preterm infants. They cause subtle deviances in postural control, and parental interaction, are a rate-limiting factor for later motor function and even academic functions such as writing and, therefore, can be regarded as a control parameter. In connection with this, Gorga and colleagues (1988) mentioned the 'fixing' phenomenon, which exists much longer in preterm infants. In our study most of the preterm children were still having difficulties with their postural control and looking for support during reaching and manipulation, however, they no longer leaned on the homolateral arm but used the heterolateral side to stabilize themselves. A high correlation between poor postural control, observable as less-coordinated trunk rotations and less-optimal arm and hand function, was still found ($p=0.0001$).

The clear connection found between arm and hand function at the age of 2 years 6 months and hand function at 39 weeks supports the assumption that poor hand function at a younger age influences the fine-tuning of muscles in a critical period of development that are needed for anticipatory and adaptive hand shaping. Nevertheless, remarkable shifts were observed; some children went from an optimal function at 39 weeks to borderline at 2 years 6 months, while in others arm and hand function improved from a non-optimal function to borderline or optimal, which could be an effect of training and learning. As often seen in follow-up studies, it is the suspect group which shows unpredictable outcomes. Many of the deviations found in this study are the consequences of being born prematurely and are not correlated to paediatric or neurological background per se. It seems that many infants improve through experience over time, but in the majority of the study group variability of movement is restricted, which at the later ages will be translated and recognized as poor coordination of functions.

A reduced or limited primary repetoire of the neural network early in life may lead to inappropriate processing of afferent information which at a later age will result in restrictions of the secondary variability of the nervous system (Edelman 1993, Hadders-Algra 2000). Self-generated movement is crucial during this stage of development. The lesser quality and poor fine-tuning of motor output to task-specific conditions exhibited by these children, may be seen as a result of the relative immobilization the young preterm infant experiences during a critical period of development. As such, the high correlation found between poor arm and hand function and non-optimal body rotations should be regarded as a more global deficit in the development of early muscle power regulation. The significant relation found between the item coordination at the age of 39 weeks and 2 years 6 months was remarkable, showing that coordination problems remained over time, reflected in an age-adequate function of reaching and manipulation. These findings seem to confirm that minor neurological deficits found in studies of older preterm children, characterized by coordination problems, show a unique association with preterm birth (Hadders-Algra et al. 1988a,b; Soorani-Lunsing et al. 1993) and in this way may contribute to learning and behavioural problems at a later age (Ruff et al. 1984).

In our study the relation between the quality of arm and hand function and the earlier hyperextension of the trunk at 39 weeks could not be reconfirmed. It seems plausible to assume that this hyperextension itself is indeed transient and disappears in most infants by learning and experience, only to reappear in a different form of muscle power deregulation at a later age and function.

Our study group was considered to be at low risk for developmental deviances and did not receive any form of programmed intervention as the health services are not inclined to pay for preventive treatment. With our data we cannot predict outcome at school age, but we are of the opinion that it is possible to detect infants at risk for subtle coordination problems at preschool age and strongly recommend an intervention program at the age of 39 weeks for children with the forementioned problems in motor development. The motor system, regulated by neurogenic and myogenic factors, enables certain behaviours and facilitates cognitive development: there is a causal and associated relationship. Discrepancies in muscle power may be transient but leave their traces, which can only be discerned when the next function in the child's development is reached and established.

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Appendix I: Scoring system used

Tone regulation of the arm
Optimal score: infant moves arm straight to object.
Slightly deviant: child moves arm, but in a clumsy way.
Clearly deviant: infant makes an obvious detour before grasping and/or replacing object and/or misses it.

Tone regulation of hand function
Relates to balance between flexor and extensor muscles in anticipation of grasping object and/or during releasing it.
Optimal score: muscle power of flexor and extensor muscles are in balance for an appropriate anticipatory and grasp or release of hand.
Slightly deviant: flexion–extension activity is not properly tuned and the anticipatory and grasp or release is badly timed.
Clearly deviant: when clearly an exaggerated extension (overshooting) of fingers is observed.

Coordination
Optimal score: if infant moves arm fluently and elegant.
Slightly deviant: movements are not very fluent and have a jerky appearance
Clearly deviant: movements are cramped, clearly not fluent and temporal sequence is not adequately matched to movement.

Associated movements
Optimal score: no extra movement on contralateral side during reaching.
Slightly deviant: there are some associated contralateral movements.
Clearly deviant: if there are definite associated movements.

Synergic movements intralimb
Optimal score: interlimb joints (i.e. shoulder, elbow, wrist) move independently from one another.
Slightly deviant: score is given in doubtful situations
Clearly deviant: joints move together in a synergic way.

Synergic movements interlimb
Optimal score: homolateral arm moves independently from heterolateral arm.
Slightly deviant: otherwise item was considered to be slightly deviant.
Clearly deviant: heterolateral side moves clearly in a synergic way with homolateral arm.

Homolateral support
Optimal score: no need for support for reaching arm or hand.
Slightly deviant: reaching hand needs support of table.
Clearly deviant: support is needed by fixing proximal joints of arm and hand on table.

Heterolateral support
Optimal score: heterolateral arm is not needed for support on table during reaching and manipulating.
Slightly deviant: heterolateral hand leans on table.
Clearly deviant: heterolateral arm, and eventually hand, is leaning during reaching and manipulating of homolateral hand.